Low Order Explosive Response

John E. DeLaney
Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV)
Code 50B21
2008 Stump Neck Road
Indian Head, MD 20640-5070
phone: (301) 744-6950, x274 fax: (301) 744-6947
E-mail: Delaney.eodtc@eodmgate.navsea.navy.mil
Award #: N0001498WX30039

Other Principle Performers:
Dr. Pat Baker, Army Research Lab (ARL), (410) 278-0204
Dr. Raafat Guirguis, Naval Surface Warfare Center (NSWC), (301) 744-6776

LONG-TERM GOALS

This program is devoted to increasing the level of understanding for non-detonative explosive reactions that are associated with main charge attack. A second goal is to develop the ability to predict the outcome of a main charge disruption procedure and to develop better tools for main charge attack. To achieve these goals, a basic understanding of the phenomenology of non-detonative reactions is being explored.

OBJECTIVES

A promising method for understanding non-detonative reactions is to explore the phenomenology with both macroscopic and microscopic approaches. The non-detonative reaction observed in testing for the EOD Main Charge Disruption (MCD) acquisition program indicated that the target's explosive fill, size, and level of confinement are important in determining the final outcome of the event, i.e., the reaction violence and effects experienced by the surrounding environment. In addition, the size, shape, material properties and velocity of the penetrators also influence the outcome. The macroscopic objective of this effort is to quantify the interaction between the above parameters and understand their effect on reaction violence of the main charge.

The microscopic approach will explore the detailed effects associated with the explosive fill. Subject areas include shear heating, growth from burn to detonation, material properties, effects of porosity, crystal morphology and rapid phase change effects on initiation and growth. Microscopic analysis will consist of tube tests, activator punch tests, closed bomb tests, special material properties evaluations, and other experiments yet to be determined that will ultimately characterize explosives and calibrate models for predictions of nondetonative reaction outcomes.

APPROACH

A series of tests and model development are planned to better understand the deflagration to detonation transition. We will perform dynamic experiments with internally instrumented 155-mm rounds to track

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the reaction and levels of pressurization in the rounds. Static tube tests with walls of varying thickness will be performed to investigate the differences in the growth of reaction for TNT and Comp B and study the effects of confinement on growth of the reaction. Dynamic tube tests with penetrator ignition are planned as well. Modeling of 155-mm tube test experiments using CTH HVRB and the Baernunzieto (BN) model for comparison are planned as well as a study of the micro effects of the explosive.

WORK COMPLETED

This year was focused on evaluating some initial baseline experimental methods and obtaining data for the growth of nondetonative reaction in both TNT and composition-B. Modeling efforts have focused on a search of current available models for nondetonative responses and initial simulation of impact events using the CTH computer code.

Experimental. Two types of experiments were conducted: first, impacts on artillery shells with embedded instrumentation, and second, soft-ignition/reaction-growth experiments of confined nonporous explosives. The latter was performed using steel tubes. In addition, an effort is underway to provide a low-pressure (0-10 kBar) calibration for carbon resistor gages. These are the primary instrumentation used to measure pressure during a nondetonative explosive event; currently, a calibration is extrapolated down from higher pressures, such as those experienced late in the transition to detonation.

Artillery Tests. Three differently sized copper rods were made to simulate the impactor sizes of the MCD. These were fired at M107 155-mm artillery shells loaded with TNT, with the impact velocity ranging from 1.1 to 2.0 mm/μs. The goals of these experiments were: (1) to try to image the nondetonative breakup of an artillery shell and gain insight into the disruption process, (2) to evaluate the use of embedded gages in observing nondetonative reactions, and (3) as a function of impactor velocity and geometry, to make temporally and spatially resolved measurements of reaction pressures and reaction front locations in a nondetonative event.

After some preliminary tests, twelve experiments were conducted. A high-speed camera was used to image the events at a nominal-framing rate of 34,000–35,000 frames/sec. Pressure inside the shell was measured using carbon resistor gages. Fiber optic cables were placed in some of the ordnance to indicate when visible light from the reaction front reached various locations within the ordnance. For the first six experiments, a single resistor gage was placed in the top of the shell at the location of the fuse well. For the latter six experiments, eight carbon resistor gages were cast into the explosive along the axis of the shell at 74 mm apart. Four fiber optic cables were also cast into these shells.

All twelve of the shells experienced low-order disruptions, with the violence varying from a 1.66 pound equivalent yield to an 8.92 pound equivalent yield. The lowest yield was obtained with a 78mm long x
6.4mm diameter copper rod traveling ~2 mm/μs, and the highest with a 37mm long x 11.9mm diameter copper rod at ~2 mm/μs. Other experiments had lower impact velocities and had intermediate yields.

Tube Tests. In an effort to perform more fundamental experiments of nondetonative reaction, tube experiments have been conducted. In a tube experiment, the explosive is cast into a confining tube that is then plugged at both ends. The explosive is initiated at one end and, by any one of several instrumentation techniques, the reaction is observed to grow or diminish as it propagates along the tube. This year our efforts were focused on reaction growth of both TNT and composition-B explosives as a function of confinement. This type of experiment is expected to be a mainstay of the low-order explosive response program throughout its duration. Thus, a second primary objective of this year was to determine what instrumentation techniques provide the most useful information with respect to pressure, reaction rate, and phenomenology. High-speed photography, carbon resistor gages, shorting pins, strain gages, fiber optics, and blast measurements are being evaluated. Each has advantages and disadvantages in terms of ease of use, analysis required, cost and time of application, being unobtrusive, and being embedded. We have completed strong confinement experiments. Currently, instrumentation is being applied to some weaker confinement tubes and others are being cast for experiments. These experiments will be completed in October/November of FY99.

To date, after some initial tests to determine an appropriate soft-ignition methodology, nine tube tests have been conducted. These tubes had a two-inch internal diameter, a one-inch wall thickness, and a 24-inch-long explosive column. Four were loaded with composition-B and five were loaded with TNT. Inside the explosive, eight carbon resistor gages were placed 76 mm apart. The resistor gages were placed in the tube through holes in the side; observation of these holes with high-speed film provided some information on reaction rate. On most of these experiments, shorting pins were placed one-quarter inch from the side of the tube along the length. High-speed film was taken of each tube at a rate of ~28-29 μs per frame, and a blast gage was used to measure the yield from the tube.

Modeling. To date our efforts have focused on reviewing existing modeling techniques and performing some simulations of our initial experiments using the CTH simulation package. We have visited the Lawrence Livermore, Los Alamos, and Sandia National Laboratories to learn about efforts that may be relevant to modeling low-order reaction of explosives.

Sandia has efforts with the greatest direct relevance to our work. They have a program to develop "validated" models for initiation and propagation of burning reactions in energetic materials. This program stems from the earlier Navy funded PHTAP program, under which a large amount of propellant damage data was collected. Though the propellant for which the VID model was developed has significantly different mechanical and chemical properties from our explosives of interest, these models may still be applicable to our scenario. To use these, only selective features of these models will be used and perhaps some additional features will be added. A "proof-of-principle" computation has been scheduled for completion in the first quarter of FY99 for Gene Hertel's effort.

This year we have run several CTH simulations of penetrator-attack against Composition-B-filled M107 projectiles. This is a very large problem, and, so far, we have only completed computations using a relatively coarse (2.5mm) zoning with inert targets. A computation with 1mm square zones and a full reactive target was started but has not yet progressed substantially. This zoning is probably the largest that can be used to describe initiation. Such problems require CPU times that are greater than the mean times between system failures and must be restarted frequently. A better strategy is to decrease run times by truncating the target, using variable zoning to concentrate zones near the penetrator path, and running on more than one processor. It should be noted, however, that when the appropriate models are developed, truncated targets couldn't be used for full reactive calculations of the low-order disruption process. The entire round becomes important in such a scenario. Advances in computer capability along with developing efficient models may alleviate this problem as this effort progresses.

RESULTS

Analysis of results is in progress and an official report is forthcoming. Preliminary results of the tube tests and artillery experiments are below.

In the artillery experiments, the lowest yield resulted from the rod perforating both sides of the shell. The exit hole provides a location for fracture and venting to begin quickly. This was evident in the high-speed film. For the highest yield shot, longitudinal cracks appeared in the rear of the shell less than 400-500 μs after impact. Cracks were not observed this rapidly in any other experiment. Detonation was not evident at this point. Fiber optic and carbon gage records for the two shots were similar, with visible light indicated at the bottom of the round in less than 400 μs. Carbon gage records showed pressures of ~4 kBar throughout the explosive in less than 300 μs. Thus, we conclude that, even early in the combustion process, venting is very important in determining the overall reaction.

The test tube experiments have shown significant differences between Composition-B and TNT. Composition-B's reaction has run to detonation, while the TNT reaction has remained nondetonative over the length of the tube, though it is growing in strength. During analysis, an upper reaction-velocity limit was taken to be the detonation velocity. Given that criteria, composition-B clearly transitions to detonation. Recovered fragments from the tubes, shorting pin data, and resistor gage data supported this conclusion.

Analyses of these data are continuing as additional data are being obtained. Pressure data from these experiments should provide information on reaction rate as a function of pressure. Based on results from these experiments, improved carbon gage mounting techniques are being used for the next phase of experiments.

IMPACT/APPLICATIONS

The phenomenology of non-detonative reactions for explosives has been an area of interest as far back as the 1880s and the invention of explosives. The goal of this program is to research past work done in this area; conduct new experiments that will help solve still unknown areas of the problem; and develop a predictive model that will help the EOD community solve current and future problems that exist in the world today. This work has had some impact already on the MCD program, which has evaluated tool concepts and is devoted to deployment of a new tool and procedures for field operations. Future impact will come in the area of higher energy explosive fills, confinement, insensitive fills, mechanical damage, mechanical properties, porosity, and development of predictive models and codes for non-detonative events.

TRANSITIONS

Work from this program has already been transitioned to the existing MCD effort. Tool developers are using the experimental knowledge gained to improve the current generation tool design and procedures for use. At the conclusion of the effort, an understanding of non-detonative process will permit an improved MCD to be developed in an EOD acquisition effort.

RELATED PROJECTS

NSWC Indian Head Division is currently conducting an explosive response program that is addressing some internal problems associated with non-detonative reactions in warhead designs. They have broken the problem up into five areas: (1) Mechanical pre-stress and strain (2) Ignition (3) Growth (4) Interfaces and (5) Reactive Flow. They believe that areas 1, 2, and 3 should not be handled by a pure Euler or ALE code. Some codes that were suggested were Epic and Dyna. Areas four and five can be handled by an Euler or ALE code.

The Department of Energy is exploring non-detonative reaction research for advance explosive applications. Los Alamos National Laboratory is conducting experiments on damage of explosives and we hope to convince them to look at TNT and Composition B for Department of Defense Applications.

The Air Force has a program at Eglin AFB for penetration survivability. Dr. Joseph Foster is exploring mechanical insult of explosives and has added some new modules to the HULL code for penetration modeling.

ARL internal funded 6.1 research for shear initiation using lasers.

REFERENCE

Proceedings of the Detonation Symposium, 1998, held at Snowmass, CO, 1 Sep 98.